Water Quality Report: 2005 Quabbin Reservoir Watershed Ware River Watershed

Photo: Quabbin Reservoir spillway. (Clif Read, January 2006)

May 10, 2006

Massachusetts Department of Conservation and Recreation
Office of Watershed Management
Division of Water Supply Protection

ABSTRACT

This report is a summary of water quality monitoring results from twenty-seven surface water stations established throughout the Quabbin Reservoir and Ware River watersheds. The Department of Conservation and Recreation, Division of Water Supply Protection (formerly the Metropolitan District Commission, Division of Watershed Management) is the state agency charged with the responsibility of managing Quabbin Reservoir and its surrounding natural resources in order to protect, preserve and enhance the environment of the Commonwealth and to assure the availability of pure water to future generations. As part of this effort, the Environmental Quality Section maintains a comprehensive water quality monitoring program to ensure that Quabbin Reservoir and its tributaries meet state water quality standards. As part of this task, the Environmental Quality Section performs the necessary field work, interprets water quality data and prepares reports of findings. This annual summary is intended to meet the needs of the decision makers, the concerned public and others whose decisions must reflect water quality considerations.

Quabbin Reservoir water quality in 2005 satisfied the requirements of the Filtration Avoidance Criteria established under the Environmental Protection Agency (EPA) Surface Water Treatment Rule. Monitoring of tributaries is a proactive measure aimed at identifying general trends and problem areas that may require additional investigation or corrective action. Compliance with state surface water quality standards among the tributaries varied with minor exceedances attributed to higher pollutant loads measured during storm events, wildlife impacts on water quality, and natural attributes of the landscape.

The appendix to this report includes summary information on mean daily flows of gaged tributaries, water quality data summary tables, plots of reservoir water quality results, and more detailed maps of sample site subwatersheds. Some of the ancillary data presented in this report has been compiled with the help of outside agencies (e.g., U.S. Geological Survey) and other workgroups inside of the DCR whose efforts have been acknowledged below.

Acknowledgments:

This report was prepared by the Quabbin Environmental Quality Section of the DCR, Division of Water Supply Protection. Scott A. Campbell, Environmental Engineer II was the principal author of this report. The author acknowledges the following who contributed to the development of this report:

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1.0 INTRODUCTION

Figure 2 shows the Quabbin Reservoir, Ware River and Wachusett Reservoir watershed system that supplies drinking water to Boston and 49 other communities that make up the MWRA service territory. The largest of the three interconnected sources, Quabbin Reservoir, is capable of holding 412 billion gallons of water. Because of Quabbin's size, it required seven years after the damming of the Swift River in 1939 before the reservoir was completely filled. The reservoir surface is best described as two interconnected fingers; the larger eastern finger stretches about 18 miles in length and has a maximum width of roughly 4 miles. The western finger stretches about 11 miles in length and has a maximum width of roughly 1 mile. In total, the reservoir surface area covers 39 square miles (25,000 acres) and contains 118 miles of shoreline. Quabbin Reservoir water transfers to Wachusett Reservoir via the Quabbin Aqueduct Intake at Shaft 12 typically account for more than half of the of MWRA's system supply. In 2005, transfers to Wachusett Reservoir totaled 37,560.44 million gallons. In the 147 days that transfers occurred, the Quabbin Aqueduct delivered an average of 255.51 MGD. A much smaller amount of water is transferred directly to three western Massachusetts communities via the Chicopee Valley Aqueduct at Winsor Dam. In 2005, the CVA Aqueduct delivered on average 8.75 MGD of flow to the CVA communities. The reservoir maintained a normal operating level throughout 2005, continuing what has been steady state of recovery from below normal levels last experienced in early 2003. In 2005, the reservoir had a net storage gain of 39,200 MG and operating levels experienced a maximum fluctuation of 5.30 feet. Daily fluctuations in reservoir water level during the past two years are depicted in **Figure 1** below.

Figure 1 - Quabbin Reservoir Daily Elevation

01/01/04 – 12/31/05

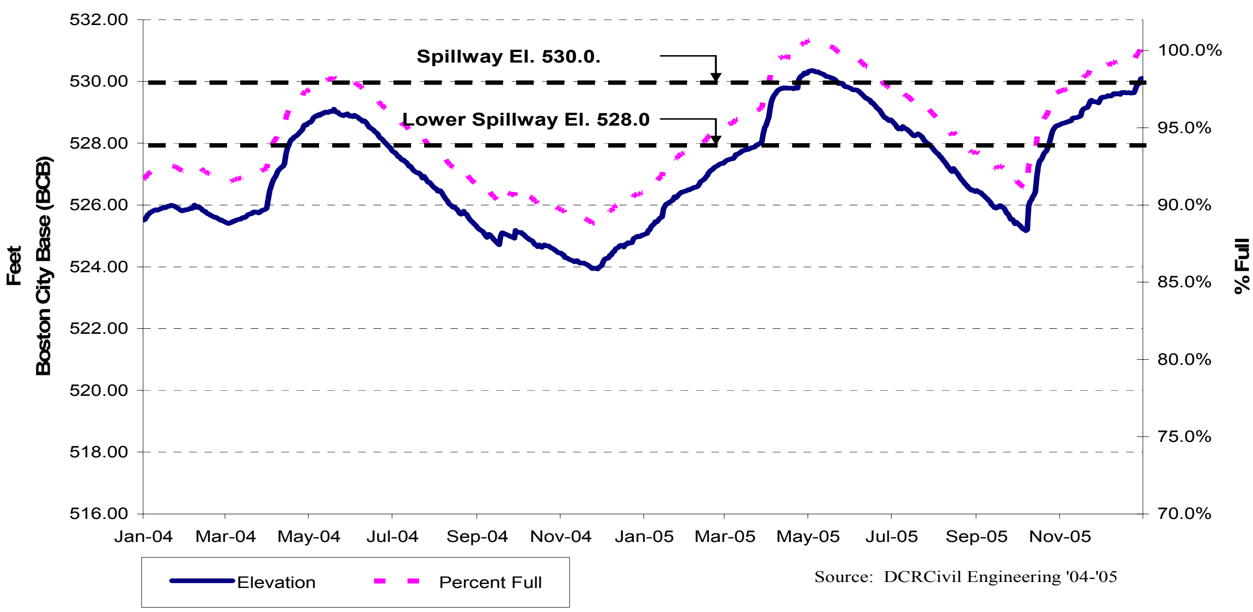
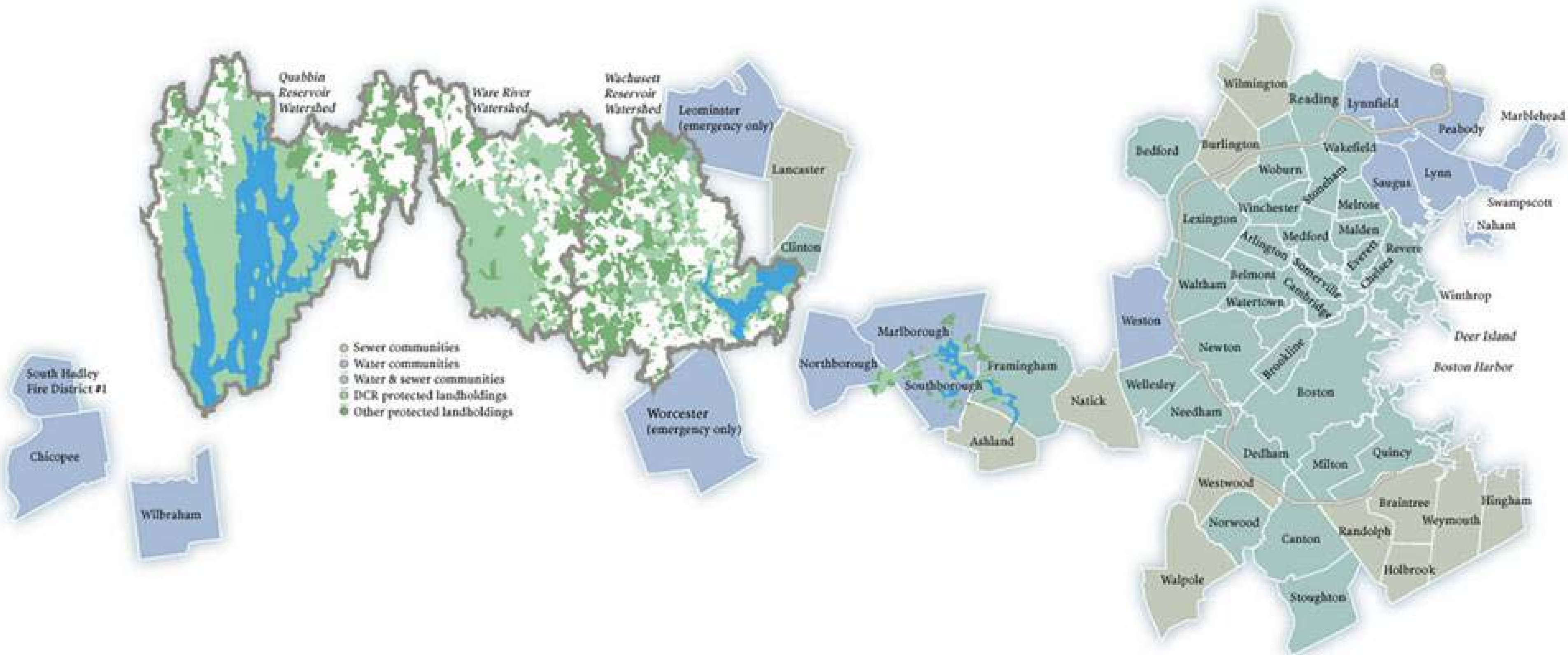


Figure 2. Quabbin Reservoir, Ware River and Wachusett Reservoir Watershed System



Source: MWRA, 2006

Table 1 - QUABBIN RESERVOIR FACTS AND FIGURES

FACTS ABOUT THE RESERVOIR		FACTS ABOUT THE WATERSHED	
Capacity	412 Billion Gals	**Watershed Area**	120,000 acres
Surface Area	24,000 acres	**Land Area**	96,000 acres
Length of Shore	118 miles	**DCR/OWM Land**	53,000 acres
Maximum Depth	150 feet	**% DCR/OWM Owned**	55%[1]
Mean Depth	45 feet	**Forested Lands**	83,235 acres
Surface Elevation	530 feet	**Wetlands**	5,289 acres
Year Construction Completed	1939	**Avg. Reservoir Gain From 1" of Precipitation**	1.6 Billion Gallons

Calendar Year:	***2005***	***2004***	***2003***
Maximum Reservoir Elevation (ft)	530.35 on May 3 & 4	529.10 on May 19	526.62 on June 29
Minimum Reservoir Elevation (ft)	525.05 on January 1	523.93 on November 28	517.61 on January 1
Total Diversions to Wachusett Reservoir	37,560.44 MG (147 days: 255.51 MGD)	58,749.68 MG (271 days: 216.8 MGD)	41,618.7 MG (177 days:235.1 MGD)
Total Diversions to CVA	3,195.5 MG (365 days: 8.75 MGD)	3,053.8 MG (366 days: 8.34 MGD)	3,029.6 MG (365 days: 8.3 MGD)
Ware River Transfers	2,992.1MG (14 days: 213.7 MGD)	5,335.8 MG (21 days: 254 MGD)	16,202.8 MG (100 days: 162 MGD)
Spillway Discharges	22,093.25 MG (169 days:130.7 MGD)	2,417.47 MG (71 days: 34 MGD)	NONE
Total Diversions to Swift River	32,673.25 MG (89.5 MGD)	11,302.47 MG (30.9 MGD)	9,236.4 MG (25.3 MGD)
Reservoir Ice Cover	≈100% cover: January 29 through April 10 (71 days).	≈100% cover: January 22 through April 2 (71 days).	≈100% cover: January 21 through April 7 (76 days).

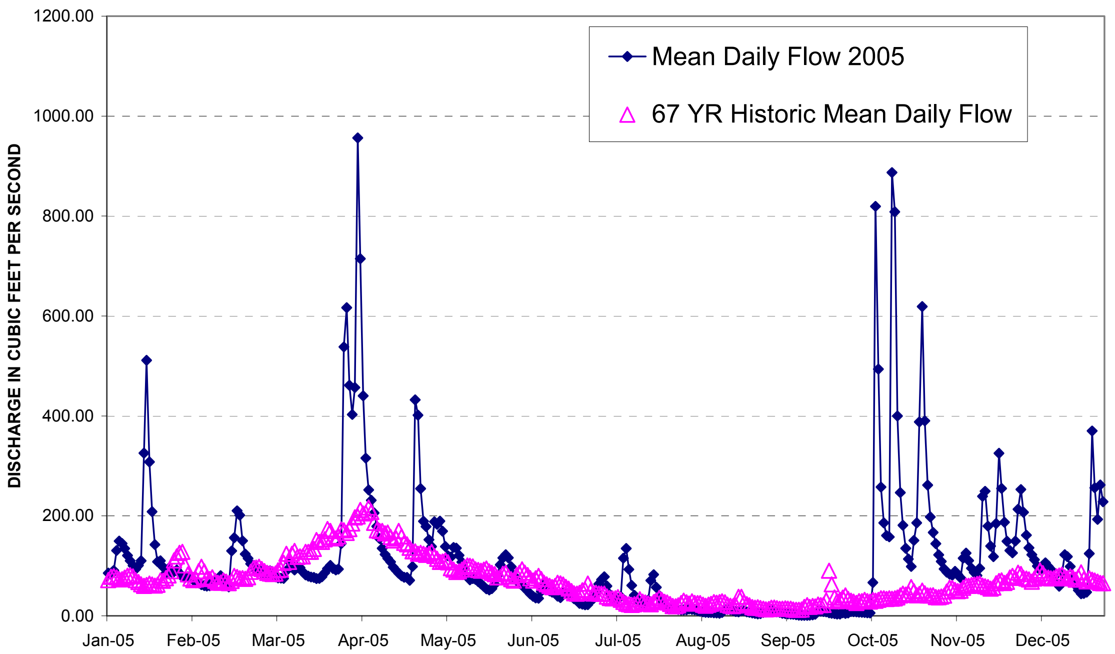
Notes:

- Source: DCR Civil Engineering Yield Data 2003-2005
- Excludes reservoir surface area.
- (….) – Denotes number of days and average daily flow.

The Quabbin Reservoir watershed itself covers 187.5 square miles (120,000 acres) and contains practically all of the towns of New Salem and Petersham, considerable portions of Pelham, Shutesbury, and Wendell, and much smaller portions of Orange, Hardwick, Phillipston, Belchertown, Ware and Athol. More than 90% of the watershed lands are forested and the Department of Conservation and Recreation, Office of Watershed Management (DCR/OWM) owns and controls 53,000 acres (55%) for water supply protection purposes. Non-DCR owned lands can be characterized as sparsely populated and having limited agricultural sites owning to the pristine character often attributed to Quabbin Reservoir water.

The eastern portion of the watershed and much of the Petersham area is drained by the East Branch of the Swift River. This 43.6 square mile subwatershed area is the largest stream tributary to Quabbin Reservoir. The US Geological Survey, Water Resources Division maintains stream gages on this and two other principal tributaries: 1) East Branch Swift River in Hardwick, 2) West Branch Swift River in Shutesbury, and 3) Ware River in Barre. In 2005, mean daily flows for the East Branch Swift River in Hardwick were measured at 109.9 cfs. No new period-of-station records were established in 2005 but annual flow increased by 162% from 2004 levels. **Figure 2** depicts the hydrograph for the East Branch Swift as measured at the horseshoe dam located at the outlet of Pottapaug Pond.

Figure 3 - EAST BRANCH SWIFT RIVER NEAR HARDWICK, MA
CALENDAR YEAR 2005



Source: U.S. Geological Survey, 2005

The western part of the watershed is principally drained by the West Branch of the Swift River. This 14.10 square mile catchment area runs north-to-south between two well-defined, steeply sloped ranges. Steeply sloping ground, shallow soils and a narrow drainage area combine to generate runoff that is extremely quick and stream flows are typically characterized as flashy . In 2005, mean daily flows for the West Branch Swift River averaged 38.7 cfs. Mean daily flows set new period-of-station records (dating back to 1995) for monthly maximums in January, April, July, October, and November.

Water from Ware River may supplement Quabbin Reservoir supplies by being diverted into the Quabbin Aqueduct at Shaft 8 in Barre and directed west towards Quabbin Reservoir via gravity flow. Under the authority granted by chapter 375 of the Acts of 1926, the DCR is limited in the diversion of the water from the Ware River to a period from October 15 to June 15, and at no time is diversion allowed when the flow of the river at the diversion works is less than 85 MGD. Water from the Ware River enters the reservoir at Shaft 11A, located east of the baffle dams in Hardwick. In 2005, Ware River transfers to Quabbin Reservoir totaled 2,992.1 MG over the course of 14 days. Transfers occurred during a short period in October to alleviate flooding in the Ware River. Mean daily flows measured on the river at the intake works in Barre, Massachusetts averaged 249.56 cfs (161 MGD) and no new period of station records were set in 2005.

Watershed runoff for 2005 was generally above normal with the USGS assigning an above normal flow rating to indexed streams for five out of the twelve months of the year. Watershed runoff was assigned a normal rating for four months out of the year (January, February, May, and June) and only during the months of March, August and September were regional stream flow conditions characterized as below normal. But, perhaps the best barometer that could be used to gauge the degree of "wetness" is when you consider that for only the second time since its creation, the elevation of Quabbin Reservoir topped the 530 elevation twice in the same year (once in May and again in late December). The last time that elevation 530 was topped twice in one year was in 1996. Like 1996, both annual precipitation and October precipitation totals ranked among the top ten for the period of record at the Belchertown station (DCR, 2005). The rainfall total of 15.77 inches for October 2005 established a new record high precipitation total for the month at the Belchertown monitoring station. In fact, only the monthly precipitation total of 22.96 inches in August 1955 exceeded the October 2005 total for the 67 year period of record. Overall, 2005 ranks as the 8th wettest year on record as measured at the long-term-precipitation recording station located in Belchertown.

2.0 METHODOLOGY

This report presents water quality data results from routine sampling performed at thirty three surface water monitoring stations located throughout the Quabbin Reservoir and Ware River watershed. There are a number of forces driving the need for a comprehensive water quality monitoring program, and they include:

1) To maintain long term water quality statistics for the significance in terms of public health protection that they provide.
2) To satisfy watershed control criteria applicable to the filtration avoidance requirements stipulated under the EPA's Surface Water Treatment Rule.
3) To identify streams and waterbodies that do not attain water quality standards where specific control measures may be initiated to eliminate or mitigate pollution sources.
4) To conduct proactive surveillance of water quality trends and potential trouble areas.

Sample Station Locations

The twenty-seven surface water monitoring stations routinely monitored in 2005 include all major tributary inflows to Quabbin Reservoir and most minor tributaries flowing to the Quabbin Reservoir or Ware River. The locations of the surface water monitoring stations are depicted in **Figures 4 and 5**. In 2005, fourteen stations were located throughout the Quabbin Reservoir watershed. An additional ten tributary stations located in the Ware River watershed are sampled to characterize this supplemental source water supply. Three reservoir stations were also monitored monthly during the months of April thru December. **Tables 2 and 3** present drainage area characteristics for the tributary surface water stations.

Data Collection

Each station is sampled biweekly (happening once every two weeks) with sampling runs alternating between the two watersheds. Samples are collected by hand at the beginning of the work week (typically Tuesday) regardless of weather conditions thereby providing a good representation of various flow conditions and pollutant loadings. The frequency of sampling gives a more complete assessment of tributary health as all seasonal flow conditions are represented and both dry and wet weather flows are captured. Tributary stream temperature, dissolved oxygen, pH and specific conductance levels are determined in the field using a Eureka Multiprobe meter. Data is stored digitally using a Eureka Amphibian PDA (personal digital assistant) and transferred to a Microsoft Access database.

In CY 2005, Quabbin laboratory staff collected 2,476 source water samples. Of those samples; nearly one-third (766) were collected for microbial analysis, roughly one-quarter (665) were collected for chemical analysis, and the remaining 1,045 samples were collected for nutrient analysis. Over 4,500 individual analyses were performed on these samples and roughly one-quarter (28%) were nutrient analyses performed at the MWRA Deer Island Laboratory. The remaining analyses were split between physiochemical parameters (1,606) and bacterial analyses (1,659) performed by MWRA staff at Quabbin laboratory. MWRA staff at Quabbin laboratory also processed and analyzed 362 microbiological samples collected at the Winsor Disinfection Facility. In addition, more than 1,400 physiochemical measurements were collected in the field by DCR staff using a Eureka Manta Multiprobe. All records are maintained in permanent bound books and in a digital format (Mircosoft Access database).

Table 2 QUABBIN RESERVOIR TRIBUTARIES
2005 SURFACE WATER MONITORING STATIONS

Tributary	DCR Sample Site #	Sample[1] Frequency	*Basin Characteristics*		
			Drainage Area (sq. miles)[2]	% Wetland Coverage[3]	% DCR/OWM Owned Land[4]
East Br. of Swift River @ Rt. 32A	216	BW	30.3	10.4%	1.7%
West Br. of Swift River @ Rt. 202	211	BW	12.4	3.4%	33.0%
West Br. of Swift River (Sibley Branch)	211E	BW	3.85	1.2%	42.4%
West Br. of Swift River (New Boston Branch)	211F	BW	6.84	4.0%	44.7%
West Br. of Swift River @ (Cooleyviile Branch)	211G	BW	1.45	1.2%	51.0%
Middle Br. of Swift River @ Gate #30	213	BW	9.14	8.1%	22.7%
Middle Br. of Swift River @ Fay Road, New Salem	213A	BW	2.74	12.85%	<1%
Middle Br. of Swift River @ Elm Street, New Salem	213B	BW	4.76	4.62%	15.5%
Hop Brook Inside Gate 22	212	BW	4.52	2.5%	32.0%
Hop Brook @ Gate 22	212A	BW	0.94	2.32%	36.2%
Hop Brook @ Gate 24	212B	BW	3.39	2.68%	31.0%
East Br. of Fever Brook @ West Road	215	BW	4.15	11.5%	12.3%
Gates Brook @ mouth	Gates	BW	0.93	3.2%	100.0%
Boat Cove Brook @ mouth	BC	BW	0.15	<<1%	100.0%

Notes:

[1]BW = biweekly meaning happening once every two weeks. Prior to May 1990 tributaries were monitored on a weekly basis.

[2]Source: Massachusetts Geographic Information System, Executive Office of Environmental Affairs. Latest revision 3/90.

[3]Source: DEP Wetland Conservancy Program (interpreted from 1:12000 Spring 1992-93 photos, latest revision 4/96).

[4]Source: Automated by Massachusetts Geographic Information System & MDC, latest revision 6/97.

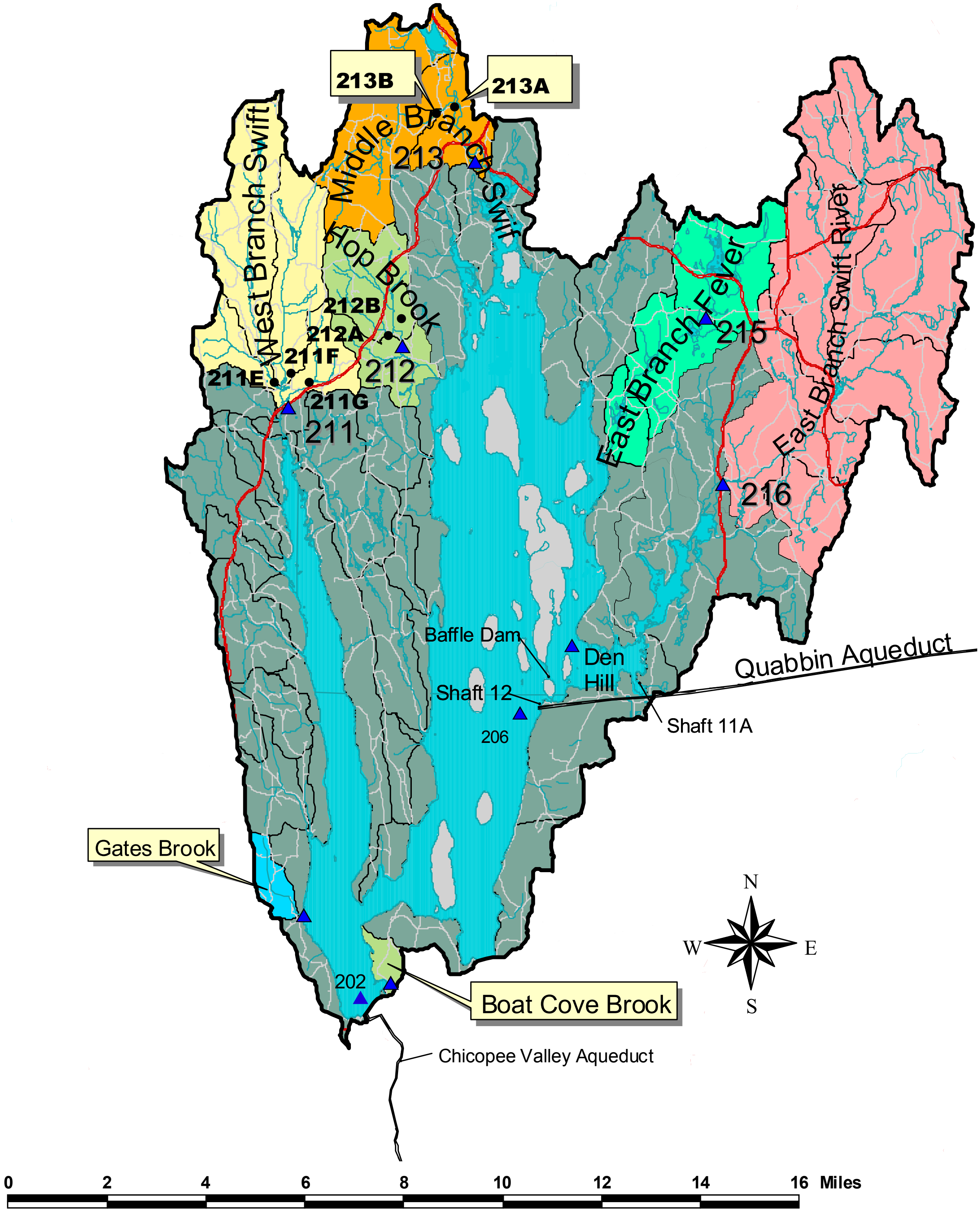


Figure 4 – Hydrology, Subwatershed Delineation and Locations of Core Sample Sites in the Quabbin Reservoir Watershed (DCR, 2005).

Table 3 WARE RIVER TRIBUTARIES

2005 SURFACE WATER MONITORING STATIONS

Tributary	**DCR Sample Site #**	**Sample Frequency [1]**	***Basin Characteristics***		
			Drainage Area (sq. miles)[2]	**% Wetland Coverage[3]**	**% DCR/OWM Owned Land[4]**
Ware River @ Shaft 8 (intake)	101	BW	96.5	13.2%	37.1%
Burnshirt & Canesto River @ Riverside Cemetery	103A	BW	31.15	10.5%	25.3%
West Branch Ware @ Brigham Road	107A	BW	16.64	15.1%	45%
East Branch Ware @ New Boston Rd.	108	BW	22.0	16.5%	12.3%
East Branch Ware @ Route 68	108A	BW	17.18	17.8%	10.2%
Cushing Pond Outlet @ Bemis Road	108B	BW	0.93	8.43%	52.8%
East Branch Ware River (Bickford) @ Lombard Rd	108C	BW	2.51	15.9%	0%
Asnacomet Pond @ outlet	116	BW	0.8	29.8	20.9
Comet Pond Outlet Tributary Near Clark Rd	116B	BW	1.05	27.6%	30.4%
Thayer Pond @ outlet	121A	BW	2.46	17.5%	23%

Notes:

[1]BW = biweekly meaning happening once every two weeks. Prior to May 1990 tributaries were monitored on a monthly basis.

[2]Source: Massachusetts Geographic Information System, Executive Office of Environmental Affairs. Latest rev. 3/90.

[3]Source: DEP Wetland Conservancy Program (interpreted from 1:12000 Spring 1992-93 photos, latest revision 4/96).

[4]Source: Automated by Massachusetts Geographic Information System & MDC, latest revision 6/97.

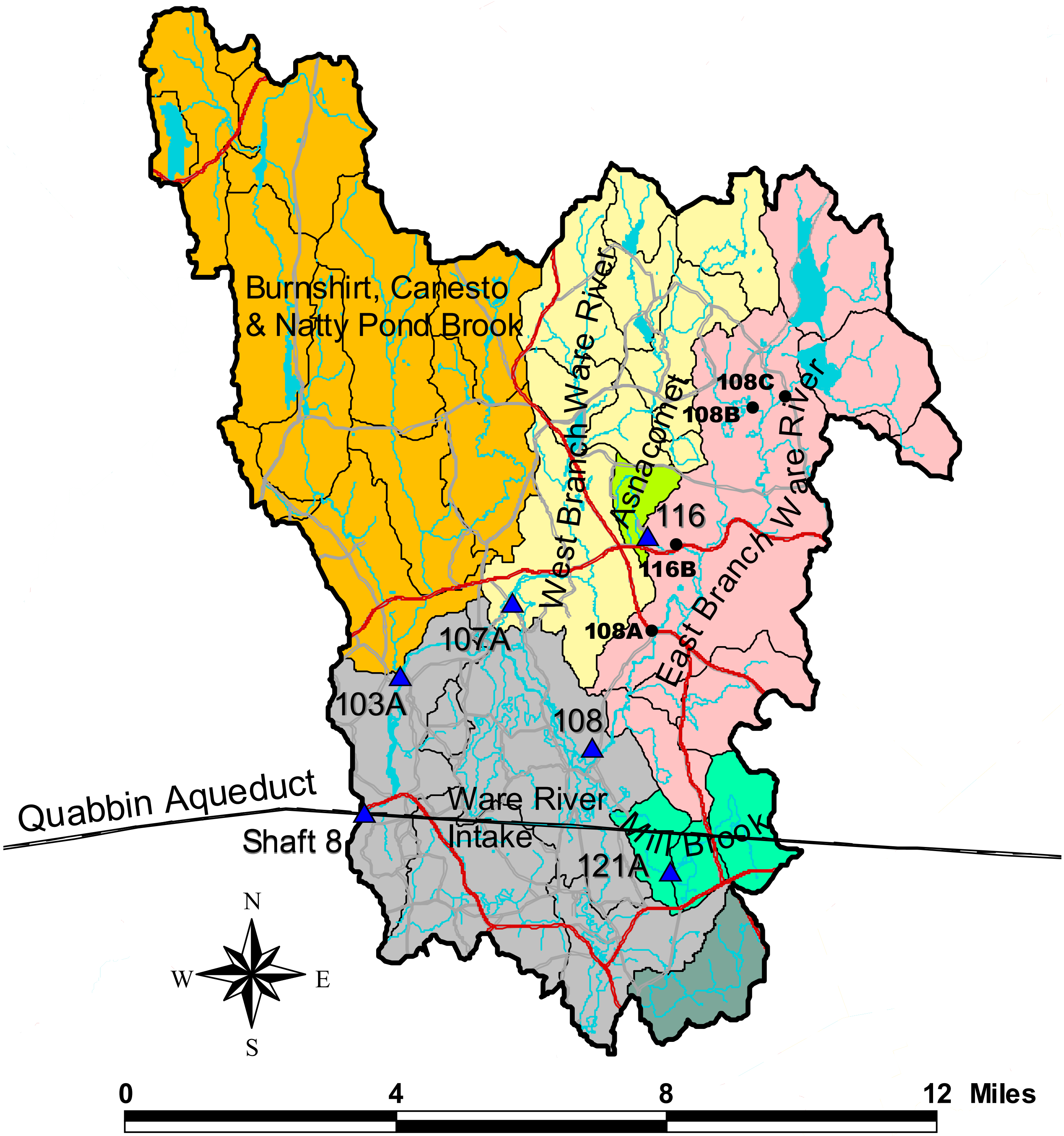


Figure 5 - Hydrology, Subwatershed Delineation and Locations of Core Sample Sites in the Ware River Watershed (DCR, 2005).

Analytical Procedures

Water quality parameters routinely analyzed include temperature, pH, alkalinity, dissolved oxygen, specific conductance, turbidity, total coliform bacteria, fecal coliform bacteria and Escherichia coli (E. coli) bacteria. **Table 4** below lists the equipment and laboratory methods employed at Quabbin laboratory.

Table 4 - QUABBIN LABORATORY: ANALYTICAL AND FIELD METHODS

PARAMETER	STANDARD METHOD (SM)[1]
Turbidity	SM 2130 B
pH	Eureka Manta Multiparameter Probe
Alkalinity	SM 2320 B (low level)
Conductivity	Eureka Manta Multiparameter Probe
Temperature	Eureka Manta Multiparameter Probe
Dissolved Oxygen	Eureka Manta Multiparameter Probe
Total Coliform	SM 9222B, SM 9223B (Enzyme Substrate Procedure)
Fecal Coliform	SM 9222D
Escherichia coli (E. coli)	SM 9223B (Enzyme Substrate Procedure)

[1]Standard Methods for the Examination of Water and Wastewater, 20th Edition

Measurement Units

Chemical concentrations of constituents in solution or suspension are reported in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit of volume of water (liter). One milligram per liter is equivalent to 1,000 micrograms per liter. Bacteria densities are reported as number of presumptive colony forming units per 100 milliliters of water (CFU/100 mL). The following abbreviations are used in this report:

CFS	Cubic feet per second
CFU	Colony forming unit
MGD	Million gallons per day
NTU	Nephelometric turbidity units
PPM	Parts per million (1 mg/L ≈ 1 PPM)
CU	Color units
TC	Total Coliform
THMFP	Trihalomethane formation potential
TKN	Total Kjeldahl nitrogen
μS/cm	Microsiemens per centimeter
μmhos/cm	Micromhos per centimeter (1 μmhos/cm = 1 μS/cm)

2005 Laboratory Changes

Significant changes were made to the Quabbin laboratory monitoring program in 2005. The most significant change involved the establishment of eleven new "EQ Assessment" sample sites where data was collected biweekly on bacteria levels, physiochemical parameters and nutrient levels. The monitoring at these special locations is scheduled to be collected through 2006 and is intended to provide supportive information for Environmental Quality Assessments (Sanitary surveys) being undertaken inside the Middle Branch Swift, Hop Brook, West Branch Swift and West Branch Ware Sanitary Subdistricts.

The tributary sampling program maintains five long-term, "core" sites located on primary tributaries inside of each watershed (Quabbin and Ware River). These core sites are important because they capture significant flow information and long term historical data will continue to be maintained. Quabbin Reservoir watershed sites discontinued in 2005 included Shaft 12 (Shoreline), Cadwell Creek, Atherton Brook, West Branch Fever Brook, and Rand Brook. Within the Ware River watershed, three historical sites were replaced with new "core" sites located downstream: the new sites include Burnshirt River at Riverside Cemetery, Thayer Pond outlet, and the West Branch Ware River at Brigham Road. Ware River watershed sites discontinued in 2005 included Queen Lake, Burnshirt River at Williamsville Pond, Burnshirt River at Route 62, Natty Pond Brook, Brigham Pond, Demond Pond, Moulton Pond, Whitehall Pond, Longmeadow Brook, Mill Brook, Canesto and Natty Brook at Route 62, and Parker Brook.

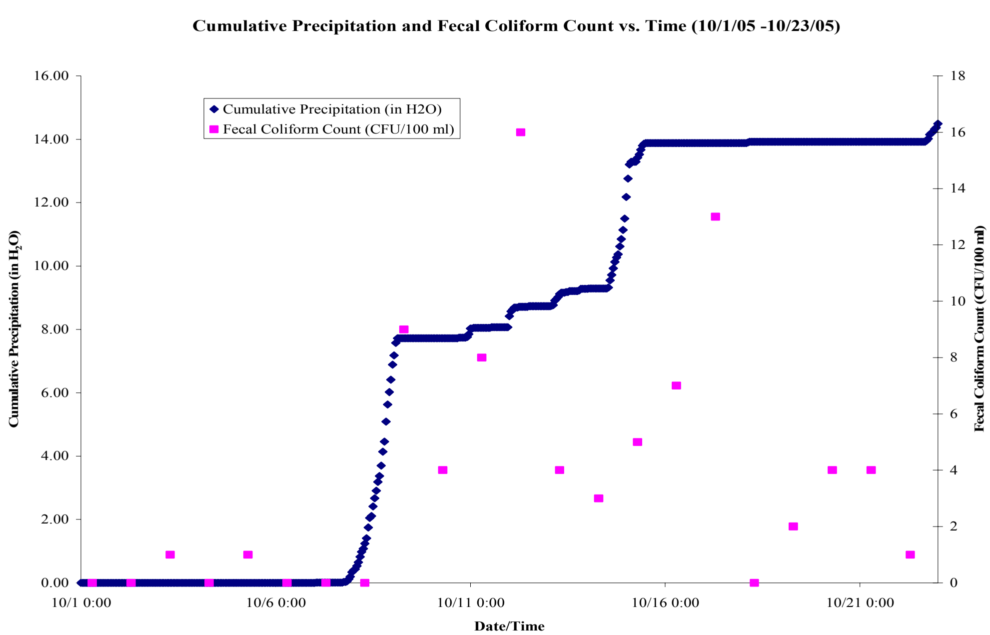
Other changes in 2005 included:

- Alkalinity monitoring was discontinued at core monitoring stations in July;
- Beginning on May 10, specific conductance and pH was no longer determined in the lab; instead, levels are determined in the field along with temperature and dissolved oxygen using a Eureka "Manta" Multiprobe; and,
- Beginning on November 8, the membrane filtration method used to determine total coliform bacteria levels was discontinued for watershed samples. The Enzyme Substrate Procedure (Colilert method) is being used instead for all watershed samples while the membrane filtration procedure will continue to be used on the Winsor Disinfection Facility (WDF) source water samples. The change in methods is significant because in side by side testing no clear correlation existed between the two methods. Nevertheless, the advantages that the Colilert method offers in its ease of sample preparation and shorter incubation time should offer greater flexibility in sampling strategies. Furthermore, the Colilert method provides information on E. coli levels which should prove a more valuable tool for bacterial source tracking than total coliform bacteria which is ubiquitous in nature.

3.0 RESULTS – SOURCE WATER QUALITY MONITORING

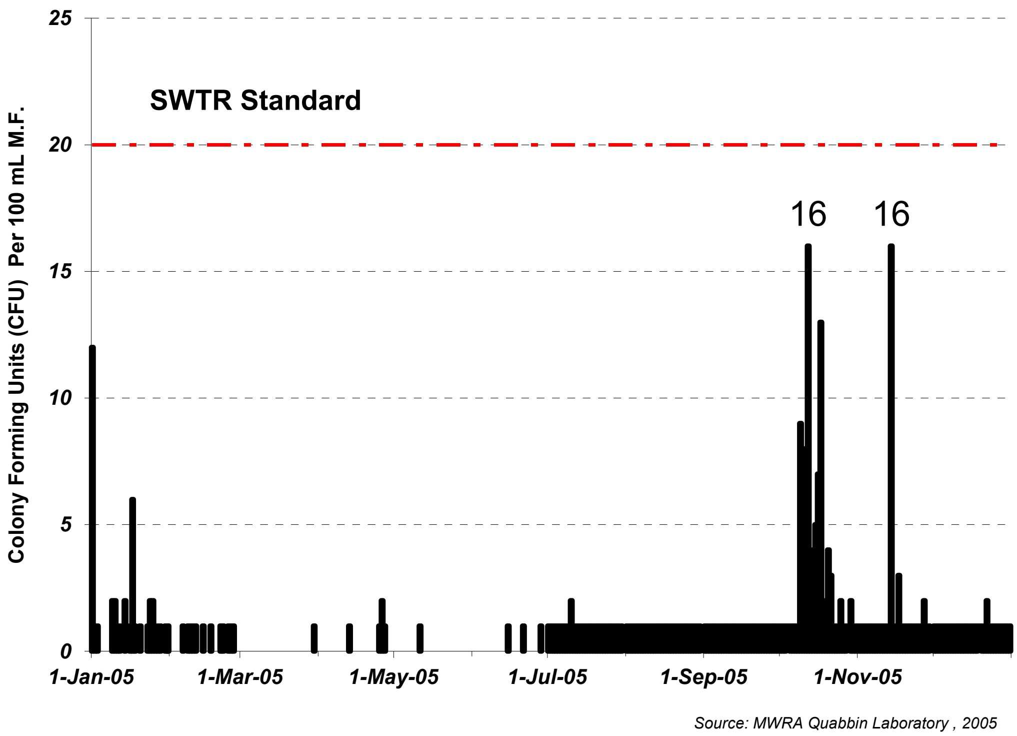
The U.S. EPA promulgated the Surface Water Treatment Rule in 1989 to ensure that public water supply systems using surface waters were providing safeguards against the contamination of water by viruses and other microbial pathogens such as *Giardia lamblia*. The regulations in effect require filtration by every surface water supplier unless strict source water quality criteria and watershed protection goals can be met. Source water quality criteria relies on a surrogate parameter, turbidity, and an indicator organism, fecal coliform bacteria, to provide a relative measure of the sanitary quality of the water. The SWTR standard for fecal coliform bacteria requires that no more than 10% of source water samples prior to disinfection over any six month period shall exceed 20 colonies per 100 mL. To ensure compliance with this requirement, the MWRA monitors daily the bacterial quality of Quabbin Reservoir water at a point prior to disinfection located inside the Winsor Disinfection Station. **Figure 7** depicts daily fecal coliform bacteria levels for 2005 and includes a horizontal line marking the SWTR limit of 20 fecal coliform colonies per 100mL. In 2005, fecal coliform bacteria levels averaged one colony per 100 mL and were absent roughly 38% of the time. The maximum level reached, 16 colonies per 100 mL, was measured on October 12 and November 14. The October 12 "event" was attributed to intense periods of rain that fell on the 8-9th and resulted in a rise in the reservoir of just about one foot over the course of twenty four hours. Rainfall totals associated with this storm exceeded eight inches and stream flooding was widespread throughout western Massachusetts. The effects from the storm can be seen graphically in **Figure 6** below as cumulative rainfall is plotted verses fecal coliform concentrations measured at the WDF facility.

Figure 6. Plot of WDF Fecal Coliform Bacteria Levels and Cummulative Precipitation During October 8, 2005 Storm Event (Reyes, 2005).



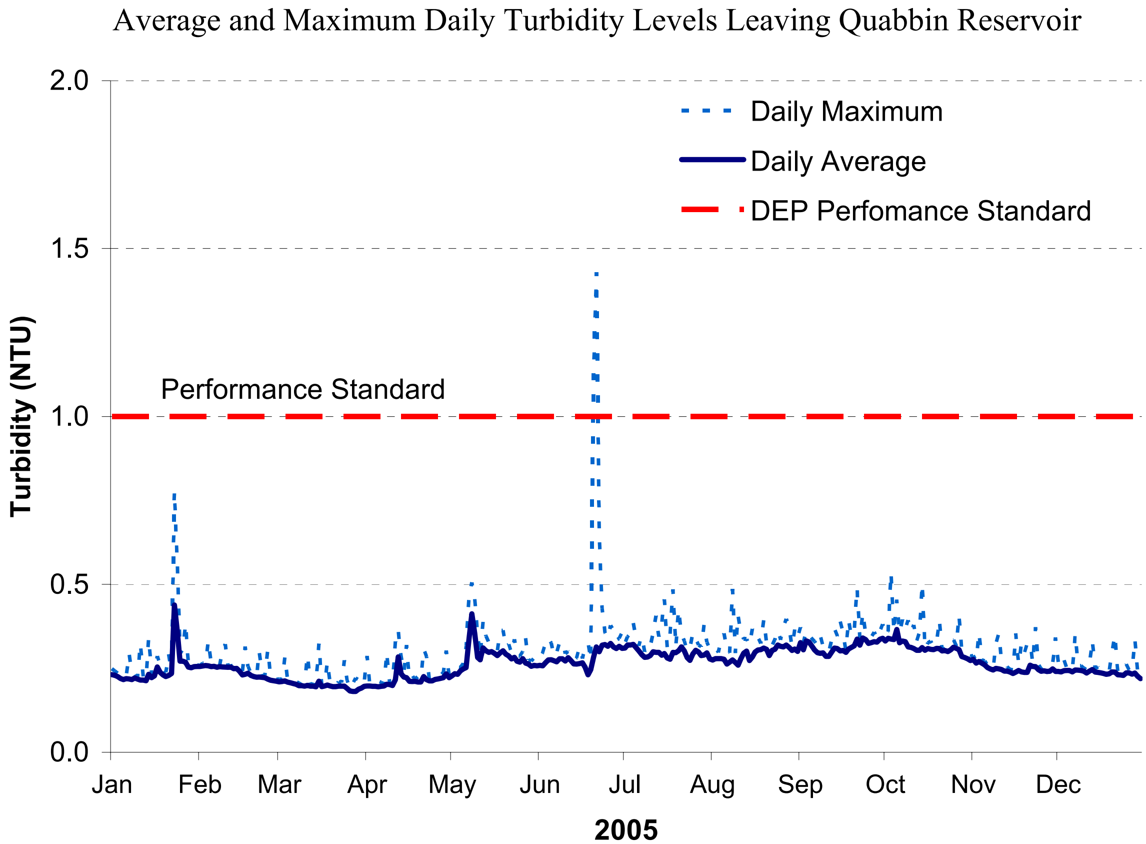
Gulls loafing on the water by the intake during the early morning hours are suspected as the source of the elevated bacteria detected in the sample on November 14. It is likely that cooling surface waters and winds during this period of falltime mixing aided in the delivery of bacteria to depths of the intake. Stepped up gull harassment measures that included early morning harassment beginning on November 17 were successful at mitigating the problem of the unwanted bird presence as indicated by decreasing bacteria levels.

Figure 7. Quabbin Reservoir Source Water Criteria: WDF Fecal Coliform Bacteria Levels Prior to Disinfection (MWRA, 2005)



For turbidity, the U.S. EPA SWTR standard is 5.0 NTU, but, the Massachusetts DEP has adopted a more stringent performance standard of 1.0 NTU. MWRA monitors turbidity levels prior to disinfection using an on-line turbidity meter located inside the Ware Disinfection Facility. **Figure 8** depicts daily maximum and average turbidity levels for 2005 and includes a horizontal line marking the 1.0 NTU performance standard. For 2005, turbidity levels averaged 0.26 NTU but turbidity spikes of 0.77, 1.127, and 1.43 NTU were observed on January 23, June 20 and June 21. From time to time, algae blooms may impart color and suspended organic particulates that will elevate levels of turbidity. Near-shore areas are also prone to elevated turbidity levels due to the action of waves that may re-suspend shoreline sediment and deposits. In each case, the turbidity spikes that occurred in 2005 were short-lived lasting only 15 minutes and high winds gusting to 47 mph on January 23 are the likely explanation for that event. Weather conditions in June make it uncertain to say whether or not algae or suspended solids were to blame for the short-lived turbidity spikes observed at that time.

Figure 8. Quabbin Reservoir Source Water Turbidity (Ware Disinfection Facility)



Giardia and Cryptosporidium monitoring on source water prior to disinfection is also conducted biweekly from a tap located inside the Winsor Power Station. These two waterborne pathogens are of concern because their cysts have a high resistance to chlorine, infectivity doses are low, and life-cycles are longer than conventional microbial pathogens. Both pathogens have been linked to waterborne outbreaks of gastrointestional disorders such as diarrhea, cramping and nausea. Sample collection and analysis follows protocols established under EPA Method 1623. In 2005, twenty-seven samples were collected by MWRA staff and sent out to specialized laboratories for analysis. All 2005 results were below the 2 cysts per 100 L detection limit and are included in the appendix of this report. Future pathogen sampling is scheduled to continue for the next two years to comply with the recently promulgated Long Term 2 Surface Water Treatment Rule. The new rule establishes levels of treatment for *Cryptosporidium* based on mean levels detected in monitoring results.

3.1 RESULTS – RESERVOIR MONITORING

Reservoir water quality data collected by the DCR documents consistently reliable source water quality that fully meets stringent Federal source water quality criteria stipulated under the

Surface Water Treatment Rule. Water quality data is collected monthly except during periods of adverse weather and ice conditions in the winter. Three sampling stations that were routinely sampled in 2005 are profiled in **Table 5**. **Figure 4** may be referenced for the specific locations of each sample site.

Table 5 - 2005 QUABBIN RESERVOIR WATER QUALITY MONITORING SITES

Site	***Location***	***Latitude Longitude***	***Approximate Bottom Depth***
Winsor Dam (QR202)	Quabbin Reservoir west arm, off shore of Winsor Dam along former Swift River riverbed.	N 42°17’15” W 72°20’59”	44 meters
Shaft 12 (QR06)	Quabbin Reservoir at site of former Quabbin Lake, off shore of Shaft 12.	N 42°22’11” W 72°16’53”	28 meters
Den Hill (QR10)	Quabbin Reservoir eastern basin, north of Den Hill	N 42°23’23” W 72°15’57”	20 meters

Reservoir water inside the three distinct reservoir basins is sampled at depth monthly between April and December (weather permitting). Water samples are collected at depth with the aide of a kemmerer bottle and samples are analyzed at Quabbin laboratory for turbidity, pH, and alkalinity. Samples for total and fecal coliform bacteria are taken at the surface, mid-epilimnion depth (typically 5-7 meters) and at the respective water supply intake depth. Physiochemical grab samples are taken from mid-epilimnion and mid-hypolimnion during times of thermal stratification, and near the top and bottom during periods of isothermy and mixing. Wind, weather, reservoir conditions and air temperature are recorded on each survey. A standard 20 cm diameter black and white secchi disk is used to measure transparency.

Water column profiles of temperature, pH, dissolved oxygen, and specific conductance are measured in-situ using a Eureka Manta Multiprobe. Readings are taken every meter during times of thermal stratification and mixing, and every three meters during periods of isothermy. Field data is stored digitally using a PDA (personal digital assistant) and transferred to a computer database maintained by the Environmental Quality Section.

Quarterly sampling for nutrients and phytoplankton was performed at the onset of thermal stratification (May), in the middle of the stratification period (late July), near the end of the stratification period (October), and during a winter period of isothermy (December). The MWRA Central Laboratory provided analytical support for the measurement of total phosphorous, total kjeldahl nitrogen, nitrate, ammonia, UV_{254} absorbance and silica.

Table 6 presents an overview of reservoir water quality conditions at three stations routinely monitored in 2005. The complete data for individual stations is included in the Appendix. Provided below is a brief discussion of selected monitoring parameters and their significance to reservoir water quality conditions.

Table 6. General Water Chemistry. 2005 Quabbin Reservoir Monitoring Stations.

	pH (Field)	**Turbidity**	**Dissolved Oxygen**	**Secchi Disk Transparency**	**Total Coliform Bacteria**	**Fecal Coliform Bacteria**
Reservoir Station	Range (units)	Range (NTU)	Range (% Saturation)	Range (meters)	Range (CFU/100mL)	Range (CFU/100mL)
Winsor Dam (QR202)	5.6-7.5	0.20-1.04	55-122	6.2-11.8	0-106	0-3
Shaft 12 (QR206)	5.8-7.5	0.19-0.61	47-115	6.3-9.8	0-43	0-2
Den Hill	5.8-7.5	0.22-0.76	31-113	3.7-7.5	1-440	0-5

Temperature

The thermal stratification that occurs in the reservoir has a profound impact on many of the parameters monitored across the reservoir profile. The temporal zones that develop within the reservoir during the warmer months of spring and summer, known as the epilimnion, metalimnion and hypolimnion (listed in order from top to bottom), have distinct thermal, water flow and water quality characteristics. Waters of the epilimnion are warm and well mixed by wind driven currents, and, may become susceptible to algal growth due to the availability of sunlight and entrapped nutrients introduced to the partitioned layer of surface water. Within the metalimnion the thermal and water quality transition occurs between the warmer surface waters and colder, deep waters. The much deeper hypolimnic waters remain stagnant, have no circulation, and serve as a sink for decaying matter and sediments that settle out from the upper layers of warmer water. Each year the reservoir is completely mixed due the settling of cooler surface waters in the fall and following springtime ice-out when an isothermal water column is easily mixed by winds. Profile data collected at Station 202 is shown in **Figure 9** to graphically portray the thermal mixing and transition that occurs between fully mixed, isothermal to fully stratified conditions. Fall overturn probably occurred during the second week of November as the water column was thermally mixed across 68% of the column at Shaft 12 and 57% of the column at Site 202 on October 27th, and, fully mixed at both locations by November 17th.

Dissolved Oxygen

Oxygen is essential to the survival of aquatic life (trout need a minimum of 5.0 mg/L or 44% saturation at 10°C). Available oxygen also plays an important role in preventing the leaching of potentially harmful metals trapped among the bottom sediments. Dissolved oxygen, or more specifically the loss of oxygen from the hypolimnion, is used is as one index to characterize the trophic state of a lake. Because re-aeration factors such as wind driven turbulence, reservoir currents, and atmospheric diffusion diminish with depth dissolved oxygen concentrations typically decrease with depth. Moreover, the raining down of decaying organic debris into the hypolimnion can be a major source of oxygen depletion in highly productive lakes because of the respiration requirements of microbial populations responsible for the decomposition of organic wastes. Hypolimnic oxygen reserves established in the spring are not replenished until the late fall when cooling surface waters ultimately settle and re-mix the reservoir. In 2005, minimum levels of oxygen reached in the hypolimnion ranged from a low of 31% saturation at the Den Hill station to 55% saturation at the bottom depths at Site 202. Depletion levels were most pronounced in the latter stages of stratification (September and October) but levels at the two deep water stations never dipped below 5.0 mg/L. The seasonal development and breakdown of lake stratification is depicted in temperature and dissolved oxygen profiles shown in **Figure 9**.

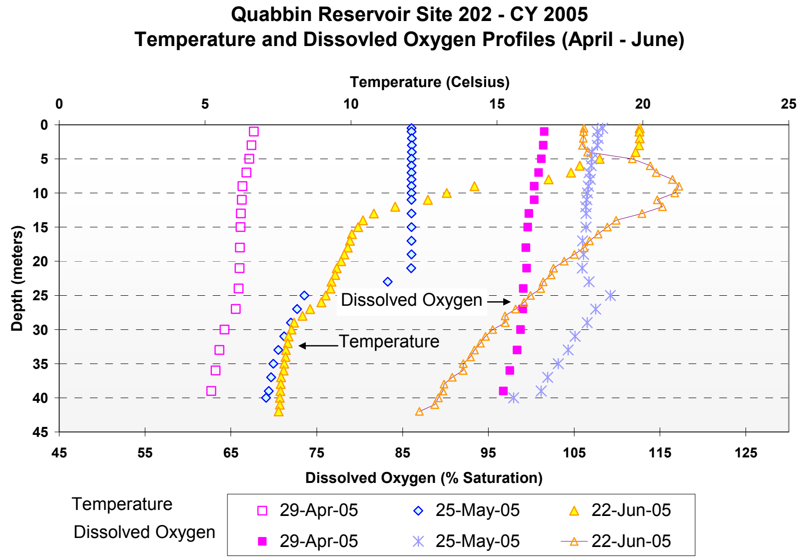
Turbidity

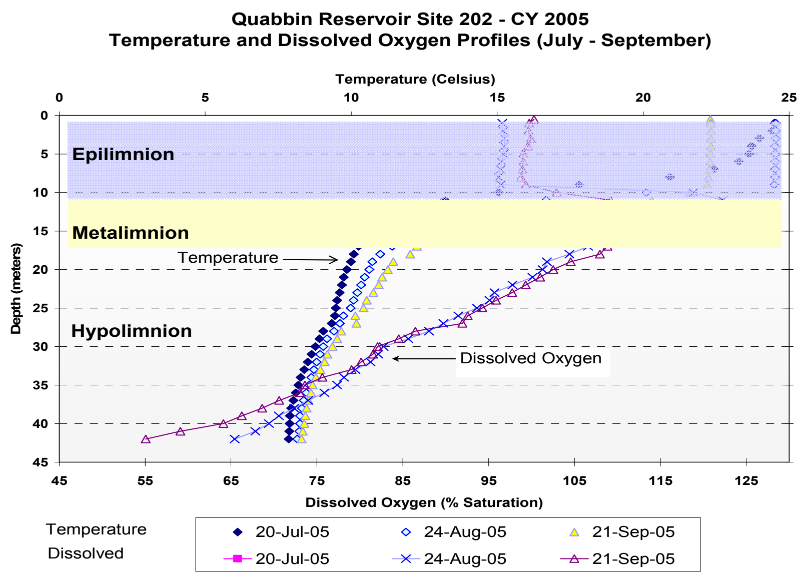
Reservoir turbidity levels are historically very low and stable, reflective of the low productivity of the reservoir. In-reservoir turbidity levels monitored in 2005 ranged from 0.19 to 1.04 NTU. From time to time, algae blooms may impart color and suspended organic particulates that will elevate levels of turbidity. Near-shore areas are also prone to elevated turbidity levels due to the action of waves that may re-suspend shoreline sediment and deposits.

pH and Alkalinity

Three processes principally reflected in reservoir pH and alkalinity dynamics are 1) direct acidic inputs (i.e., rainfall, dry deposition), 2) biological respiration and 3) algal photosynthesis. The input of acid in the form of direct precipitation will consume alkalinity available in the water and reduce pH levels. Reservoir pH is an important consideration because levels below 6 increase the solubility of persistent heavy metals such as mercury, allowing the metal to be incorporated into the water system and thus more likely to accumulate in the tissue of living organisms such as fish. As a result most northeastern lakes like Quabbin Reservoir have posted fish consumption advisories that suggest limiting the quantity of fish consumed because of the presence of higher levels of mercury in the fish. Quabbin Reservoir water is slightly acidic with a pH level that averaged 6.61 across the three stations monitored in 2005.

Alkalinity serves as a water body's principal defense by neutralizing the effects of pH. Both pH and alkalinity have a long-term record of stability in the Quabbin Reservoir but levels will fluctuate due to reservoir dynamics. Fluctuations may be caused through respiration by organisms as oxygen is consumed and carbon dioxide is released. The result will be an increase in alkalinity due to the input of carbon to the water. Photosynthetic activity in the epilimnion and metalimnion can decrease alkalinity and increase pH due to the consumption of free carbon dioxide and bicarbonate. Reservoir alkalinity is low and averaged 4.85 mg/L as $Ca\ CO_3$ across the three reservoir stations with very little variation observed at depth.





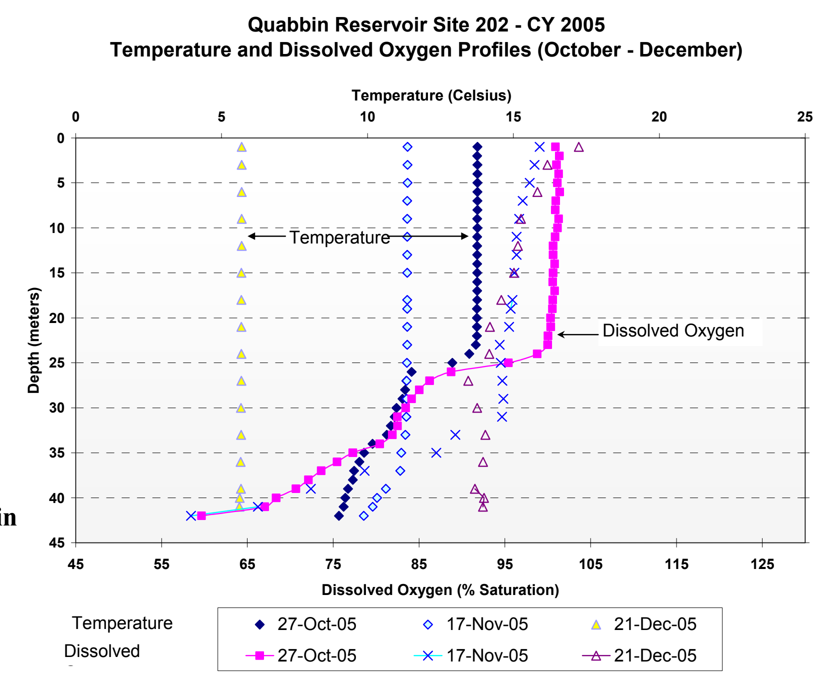


Figure 9 **Seasonal variations of temperature and oxygen at depth in Quabbin Reservoir.**

Station 202, Winsor Dam.

Secchi Disc Transparency

Quabbin reservoir water has excellent clarity and visibility as evidenced by maximum secchi disc readings that approach 13 meters. Transparency is determined as the depth below the surface at which a 20 centimeter black and white disk becomes indistinguishable to the naked eye. Transparency can be greatly influenced by the level of phytoplankton activity but is also sensitive to weather and reservoir conditions at the time of sampling. Historically, reservoir transparency measurements are consistent with the pattern of phytoplankton dynamics (Worden, 2000). In 2005, transparency was measured at a maximum of 11.8 meters at Site 202 on July 20. The Den Hill station is characteristically much lower and reflects the contribution of large, nearby river inputs of the East Branch Swift and Ware River (when diverting). The contribution of the East Branch Swift River, estimated to contribute as much as 9-16% of the annual flow to the reservoir, is a significant source of color that reduces transparency. In 2005, transparency was measured at a minimum of 3.7 meters at Den Hill on October 27. Monthly transparency measurements and weather observations are noted in the tables below.

Table 7. 2005 QUABBIN RESERVOIR SITE 202 - WINSOR DAM. SECCHI DISK READINGS WITH WEATHER AND WATER COLUMN OBSERVATIONS.

Date	Transparency (m)	Water Color	Weather & Water Surface Observations
April 29, 2005	7.0	green	Mostly sunny, West wind 5-8 mph, 6" waves.
May 25, 2005	ND	----	Cold with high winds and waves. Too wavy for secchi disk.
June 22, 2005	6.2	Light blue-green	23˚C Cloudy with light rain; 8" waves, west wind at 5-8mph.
July 20, 2005	11.8	light blue-green	Hot (32°C) and sunny; no wind and calm water surface.
August 24, 2005	8.7	light blue-green	Fair sky, 60% cloud cover, light N wind 3-5 mph with 6" chop.
September 21, 2005	9.4	light blue-green	Sunny, clear and cool; West wind 6 mph with 6" chop.
October 27, 2005	8.6	Green	Sunny, clear and cold; WNW wind 3-5 mph with 4" chop.
November 17, 2005	7.5	light blue-green	Sunny (20% cloud cover) and cool; N 5 mph wind with 6" chop.
December 21, 2005	8.2	light blue-green	Cold and partly cloudy (10%); slight ripples with a light W wind.

Table 8. 2005 QUABBIN RESERVOIR SITE 206 - SHAFT 12. SECCHI DISK READINGS WITH WEATHER AND WATER CONDITION OBSERVATIONS.

Date	Transparency (m)	Water Color	Weather & Water Surface Observations
April 29, 2005	ND	Green	Mostly sunny, West wind 10-15 mph, 1-2 foot white caps.
June 22, 2005	7.6	Light blue-green	24˚C and partly cloudy (80%); 6” waves with N wind at 5 mph.
July 20, 2005	9.6	light blue-green	Hot (32°C) and sunny; very light north wind and slightly rippled water surface.
August 24, 2005	7.6	light blue-green	Fair sky, 60% cloud cover, light N wind 3-5 mph with 6” chop.
September 21, 2005	9.8	light blue-green	Sunny, clear and cool; West wind 6 mph with 6” chop.
October 27, 2005	6.3	Green	Partly sunny, increasing clouds (70%) and cold; WNW wind 5-8 mph with 6-10” chop.
November 17, 2005	7.8	light blue-green	Sunny (20% cloud cover) and cool; N 5 mph wind with 6” chop.
December 21, 2005	9.4	light blue-green	Cold and partly cloudy (10%); 6” waves with a light SW wind.

Table 9. 2005 QUABBIN RESERVOIR SITE DEN HILL. SECCHI DISK READINGS WITH WEATHER AND WATER CONDITION OBSERVATIONS.

Date	Transparency (m)	Water Color	Weather & Water Surface Observations
May 25, 2004	5.4	yellow-green	75˚F and cloudy; calm surface with very slight southerly wind at 1 mph.
June 22, 2005	5.4	Light yellow-brown	26˚C and partly cloudy; 4” waves with N wind at 4 mph.
July 20, 2005	7.5	Light yellow-brown	Hot (32°C) and mostly sunny (20% clouds); light northwest wind 3 mph and slightly rippled water surface.
August 24, 2005	6.9	Light yellow-brown	Fair sky, 60% cloud cover, light N wind 3-5 mph with 6” chop.
September 21, 2005	7.4	Light yellow-brown	Sunny, clear and cool; West wind 6 mph with 4” chop.
October 27, 2005	3.7	Light yellow-brown	Cloudy (overcast) and cold; WNW wind 5-8 mph with 4” waves.
November 17, 2005	3.8	light yellow-brown	Sunny (10% cloud cover) and cool; N 5 mph wind with 4” chop.
December 21, 2005	No Data	No Data	No Data

Coliform Bacteria

In-reservoir coliform bacteria levels were monitored at the routine reservoir stations monthly beginning on May 25 and ending on December 13. During periods of thermal stratification, grab samples were collected from the surface, at the five meter depth, and from the respective water supply intake depth at the two deep basin sites (Shaft 12 and Winsor Dam). The term coliform is used to describe a group of bacteria based on biochemical functions and not on taxonomy. For instance, by using selective culturable media and incubation temperatures it is easy to differentiate between the total and the fecal coliform groups. Taxonomically, the two groups are very different; unlike total coliform bacteria, fecal coliform bacteria are normal inhabitants of the intestine of warm blooded animals and humans. Moreover, normally parasitic forms of the fecal coliform group do not survive more than an order of weeks in reservoirs, streams and the open environment while bacteria of the total coliform group are natural inhabitants of the aquatic system and the environment (Wolfram, 1996) (Dutka and Kwan, 1980). For these reasons, fecal coliform bacteria are the preferred choice as indicators of fecal pollution because their presence usually indicates recent pollution of the water.

Fecal coliform bacteria levels in reservoir samples are very low having ranged from zero to five colonies per 100 mL in 2005. A seasonal gull population that roosts on the reservoir overnight has been identified as the primary contributor of fecal coliform bacteria contamination to the reservoir. Other sources may include other waterfowl, semi-aquatic wildlife and tributary inputs. However, because of the long residence time of the reservoir (reported on the magnitude of several years), fecal coliform bacteria levels are normally very low reflecting die-off and predation that occurs naturally.

Reservoir total coliform bacteria are much more dynamic having ranged from zero to 440 colonies per 100 mL in 2005. Currently, a lack of a clear understanding of the natural microbial flora of the reservoir and a poor correlation of total coliform levels with reservoir fecal coliform levels (Lee, 2004) makes fecal coliform the indicator of choice for tracking contamination purposes. This approach is consistent with the EPA Surface Water Treatment Rule finding which specified that when both total and fecal coliform bacteria are analyzed the fecal findings have precedent.

Reservoir Phytoplankton and Nutrient Dynamics

The nutrient database for Quabbin Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2004 is used as a basis for interpreting data generated in 2005 (see **Table 10**). Results of quarterly nutrient sampling in 2005 documented concentrations of phosphorous and nitrate that registered at the low end of historical ranges. In contrast, silica concentrations generally registered on the higher end and in the case of the two deep water basins the 2005 ranges exceeded historical maximums. A plausible explanation for these elevated levels is that diatom populations were limited by an exceptional scarcity of phosphorous such that the typical processes of diatom growth and sedimentation did not function to remove as much silica from the water (Worden, 2005).

The other parameter with noteworthy results is UV_{254} absorbance, a surrogate parameter for the concentration of organic compounds in the water. Results for this parameter at Den Hill registered at the high end and in the case of samples collected on October 27 exceeded historical ranges. The events of October are significant as a total of 12.5 inches of rain was recorded at Quabbin Reservoir between October 6^{th} and the 18^{th}. The East Branch Swift River drains approximately 30% of the entire Quabbin Reservoir watershed and discharges into the reservoir at a distance of about 2,600 meters “upstream” of the Den Hill sampling station. Vigorous loading of dissolved organic compounds from this major tributary (combined with diversion flows from Ware River) resulted from the heavy rain events and these compounds were measured at record levels at the Den Hill station in October (Worden, 2005).

In general, the patterns of nutrient distribution in 2005 quarterly samples were comparable to those documented previously in the 2000 report on Quabbin nutrient and plankton dynamics. These patterns consist of the following: (1) prominent seasonal and vertical variations due to demand by phytoplankton in the trophogenic zone (low concentrations in the epilimnion and metalimnion) and decomposition of sedimenting organic matter in the tropholytic zone (higher concentrations accumulating in the hypolimnion), (2) a lateral gradient in silica concentrations correlated to hydraulic residence time and mediated by diatom population dynamics, (3) and slightly higher concentrations and intensities at the Den Hill monitoring station due to the loading effects of the East Branch Swift River.

Table 10 - Quabbin Reservoir Nutrient Concentrations:
Comparison of Ranges from 1998-04 Database[1] to Results from 2005 Quarterly Sampling[2] (Worden, 2005)

Table 2005 - Quabbin Reservoir Nutrient Concentrations:
Comparison of Ranges from 1998-04 Database[1] to Results from 2005 Quarterly Sampling [2]

Sampling Station [3]	Ammonia (NH_3; µg/L)		Nitrate (NO_3; µg/L)		Silica (SIO_2; mg/L)		Total Phosphorus (µg/L)		UV_{254} (Absorbance/cm)	
	1998-04	Quarterly'05	1998-04	Quarterly'05	1998-04	Quarterly'05	1998-04	Quarterly'05	2000-04	Quarterly'05
WD/202 (E)	<5 - 16	<5 - 9	<5 - 23	<5 - 14	0.84 - 1.85	1.74 - 1.98	<5 - 20	<5 - 6	0.017 - 0.025	0.024 - 0.026
WD/202 (M)	<5 - 29	<5 - 15	<5 - 27	<5 - 13	0.83 - 1.79	1.75 - 2.07	<5 - 13	<5 - 10	0.017 - 0.027	0.024 - 0.028
WD/202 (H)	<5 - 53	<5 - 21	<5 - 54	<5 - 29	1.08 - 2.58	1.87 - 2.45	<5 - 44	<5 - 8	0.017 - 0.024	0.022 - 0.026
MP/206 (E)	<5 - 8	<5 - 10	<5 - 20	<5 - 12	0.84 - 1.62	1.66 - 1.88	<5 - 12	<5 - 5	0.017 - 0.031	0.024[4]
MP/206 (M)	<5 - 34	<5 - 20	<5 - 44	<5 - 14	0.84 - 1.56	1.70 - 2.15	<5 - 12	<5	0.017 - 0.029	0.027 - 0.028
MP/206 (H)	<5 - 105	6 - 9	<5 - 95	<5 - 13	1.02 - 1.92	1.85 - 2.32	<5 - 19	<5	0.018 - 0.026	0.025 - 0.029
Den Hill (E)	<5 - 19	6 - 16	<5 - 45	<5 - 13	0.74 - 4.64	1.25 - 2.59	<5 - 15	<5	0.025 - 0.112	0.037 - 0.122
Den Hill (M)	<5 - 25	6 - 19	<5 - 58	<5 - 13	0.84 - 4.37	1.51 - 2.95	<5 - 15	<5 - 14	0.027 - 0.090	0.040 - 0.139
Den Hill (H)	<5 - 84	11 - 21	<5 - 78	15 - 22	0.83 - 4.25	2.69 - 3.46	<5 - 15	<5	0.028 - 0.103	0.045 - 0.171

Notes: (1) 1998-04 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling conducted through December 2004, except for measurement of UV_{254} initiated in 2000 quarterly sampling

(2) 2005 quarterly sampling conducted May, July, October, and December (Mt. Pomeroy/206 and Den Hill were excluded in the May sampling effort; Den Hill was also excluded in the December sampling effort)

(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

(4) Anomalous UV_{254} value of 0.093 A/cm omitted

3.2 RESULTS - TRIBUTARY MONITORING

Monitoring of tributary water quality is not required by the SWTR or other regulations but does serve to establish a baseline of water quality data from which trends may be used to identify subwatersheds where localized activities may be adversely impacting water quality.

Fecal Coliform Bacteria

2005 median fecal coliform bacteria levels at all stations fell within normal historic ranges (1990-2003) and most fell below the Class A Standard of 20 FCU/100mL. Sites with median levels at or above the Class A standard were the Middle Branch Swift at Fay Road, Hop Brook at Gate 22, West Branch Ware River at Brigham Road, Burnshirt and Canesto at Riverside Cemetery, East Branch Fever Brook, Middle Branch Swift at Gate 30, and East Branch Swift River (listed in order from highest to lowest). New historic maximum levels were recorded at two of the ten "core" sampling stations: East Branch Ware on June 28 and the East Branch Fever (2170) on September 27.

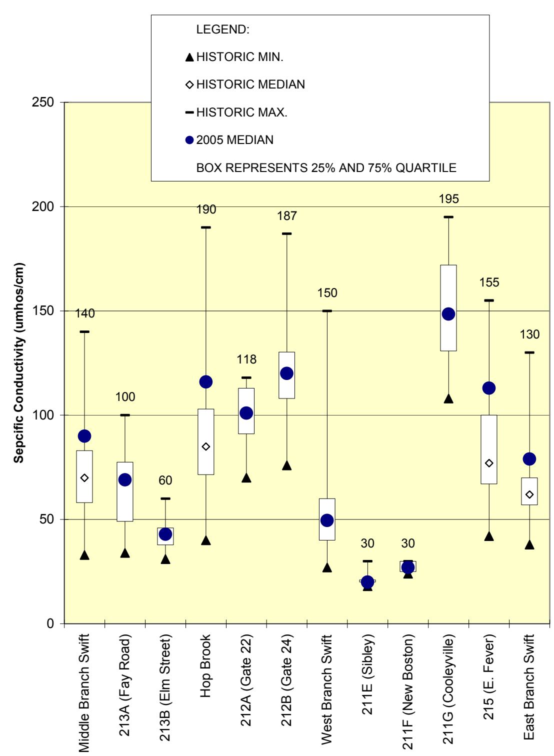
Total Coliform Bacteria

2005 median total coliform bacteria levels exceeded the historic 75% quartile level at all nine core sample stations. New historic maximum levels were recorded at four core tributary stations: Middle Branch Swift River at Gate 30, Hop Brook at Gate 22, West Branch Ware River and the East Branch Ware River at Intervale Road.

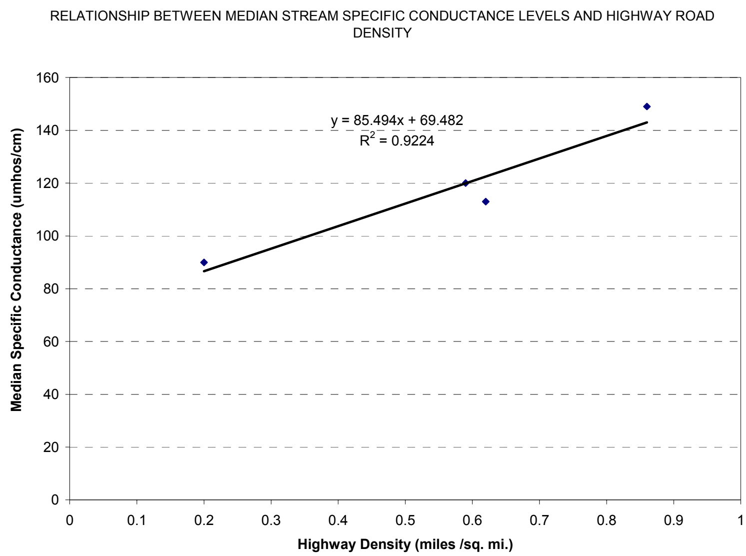
Specific Conductance

Median specific conductance levels are on the increase at most all watershed stations and correlations with road densities seems to suggest that increasing use of de-icing salts is responsible for this apparent trend. **Figure 10** compares the 2005 median values to historic levels (where established) on a selected number of Quabbin Reservoir watershed sample sites. Specific electrical conductance is the measure of the ability of water to conduct an electrical current, which is dependent on the concentration and availability of mineral ions. Elevated levels in streams may be indicative of contamination from septic system effluent, stormwater discharges or agricultural runoff. One significant source of higher levels in tributaries is chloride found in deicing salts

Figure 10. Annual Median Specific Conductance Levels in Ware River Tributaries Verses Historic Levels (1990-2003).



applied to highways and local roads (Shanley, 1994) (Lent et. al, 1998). Median specific conductance concentrations were compared at five Quabbin Reservoir watershed tributary stations whose subwatersheds contained state highways with road densities ranging between 0.2 and 0.86 miles of highway per square mile of drainage area. **Figure 11** shows the linear regression produced by comparing the median specific conductances which suggests that about 92% (r^2 = 0.92) of the variation was accounted for by the density of state highway roads. In general, 2005 median specific conductance levels exceeded historic 75% quartile levels (1990-2003) established at nearly all of the core tributary sample sites. The exceptions where 2005 levels were relatively unchanged from historic levels included sites on the West Branch Swift River, Gates Brook and the Boat Cove Brook. The subwatersheds of these drainages have low road densities and most of the roads inside the catchments are gravel surface roads where the application of road salt (if any) is expected to be reduced because of slower travel speeds and the rural character of these roads.



Dissolved Oxygen

The oxygen concentration of tributaries of Quabbin Reservoir and Ware River watershed were generally quite high. Concentrations ranged between 1.21mg/L and 19.09 mg/L. The source of dissolved oxygen in a stream environment comes from re-aeration dynamics. Dissolved oxygen levels are depleted though the oxygen requirements of aquatic life, the decomposition of organic matter, and the introduction of foreign oxygen-demanding substances (i.e., chemical reducing agents). Temperature, stream flow, water depth and the physical characteristics of the stream channel are the principal drivers of re-aeration. The Massachusetts Class A standard is a minimum of 6.0 mg/L. Qualitatively, oxygen levels were measured below the 6.0 mg/L threshold in 10% of the samples monitored within the Ware River watershed and 4.6% of the samples monitored inside the Quabbin Reservoir watershed.

Temperature

Temperature in tributaries of Quabbin Reservoir and Ware River watershed ranged between zero and 24.3˚C. Temperature is an important parameter in its relation to dissolved oxygen because as temperature increases the amount of oxygen that can be dissolved in water decreases. Moreover, higher temperatures increase the solubility of nutrients and may correlate well with an increase in the growth of filamentous green algae

Turbidity

Turbidity is the relative measure of the amount of light refracting and absorbing particles suspended in the water column. Turbidity is used as an indicator of water aesthetics and as a relative measure of the water's productivity. The Massachusetts drinking water standard is 5 NTU for source water and 1 NTU for finished water. 2005 turbidity levels exceeded the 5 NTU standard at six of twenty-four tributary monitoring stations: Ware River at Shaft 8, West Branch Ware River at Brigham Road, Thayer Pond at Outlet (121A), East Branch Swift River at Route 32A, Hop Brook at Gate 24 and at the Boat Cove Brook. The highest turbidity level recorded was 10.0 NTU measured in Hop Brook on March 29. A two inch rainstorm combined with melting snow on March 29 produced annual peak turbidities measured at seven other tributaries sampled on that day. Also noteworthy is the fact that only the small, intermittent stream known as the Boat Cove Brook experienced multiple exceedances of the 5 NTU standard (4 times).

pH

Stream acidity is largely a function of the groundwater hydrogeology of the basins and their effectiveness in buffering the effects of acid precipitation. pH is a measure of the number of hydrogen ions [H+] reported on a log scale of 0 to 14. An [H+] concentration of 7.0 represents neutral water and levels below this are considered acidic with each drop in one unit representing a 10 fold increase in acidity. Median pH values in 2005 were below the Class A water quality threshold of 6.5 units at 16 of 24 monitoring stations. Sites with median levels below 6.0 include Gates Brook, East Branch Fever Brook, New Boston reach of the West Branch Swift and the Sibley reach of the West Branch Swift.

Alkalinity

Alkalinity is a relative measure of water's ability to neutralize an acid. For comparison purposes 2005 data was compared to acid rain assessment criteria established under the Acid Rain Monitoring (ARM) Project at the University of Massachusetts. Median alkalinity (standard method) levels in 2005 were below the ARM endangered threshold value of 5 mg/L as $CaCO_3$ at twenty of twenty-four tributary monitoring sites. At three stations, Gates Brook, New Boston reach of the West Branch Swift and the Sibley reach of the West Branch Swift, average April levels were classified as critical using ARM criteria.

In June Quabbin laboratory discontinued monitoring of alkalinity on "core" sample sites. To develop baseline information, alkalinity is analyzed biweekly on samples collected from Environemntal Quality Assessment sample sites added during this past year.

Tributary Nutrient Dynamics

Beginning in March 2005, sampling begun on selected tributaries with the goal of establishing a nutrient database for each subwatershed. Aggressive monitoring (biweekly) was begun on four subwatersheds where Environmental Quality staff is actively engaged in sanitary surveys and they include: Middle Branch Swift River, Hop Brook, West Branch Swift River and the East Branch Ware River. In addition, core tributary stations were monitored on a quarterly basis. Nutrient concentrations measured in 2005 were compared with ecoregion reference conditions established as part of a national water quality assessment performed by the US EPA. Regional reference conditions (i.e., background levels) were assigned as the 25th percentile value of a ten year database begun in 1990 (US EPA, 2000). Nitrate, total kjeldahl nitrogen and total phosphorous concentrations across the Quabbin and Ware River watershed generally fell below EPA reference conditions.

UV absorbance levels were compared with historical levels established through a study undertaken between 1997 and 2000 by the University of Massachusetts (Garvey, 2000). In general, the 2005 results for the Hop Brook and Middle Branch Swift Sites registered within the range of historical data. For the West Branch Swift River, 2005 results for the Cooleyville branch fell within the historic range but levels on the Sibley and New Boston branches exceeded historic ranges. One possible explanation is the closer proximity to upstream beaver impoundments which is likely to increase dissolved organics. 2005 marked the first time that UV absorbance data was collected on Ware River tributaries. Future nutrient and absorbance monitoring is planned to continue on the biweekly and quarterly schedule in order to establish a more meaningful database.

4.0 PROPOSED SCHEDULE FOR 2006

The 2006 water quality program will see no significant changes from protocols developed over the course of 2005. The coming year will mark the first complete year in which the Colilert method (Enzyme substrate procedure) is used to obtain watershed levels of total coliform bacteria and E. coli bacteria.

Sampling on the reservoir will remain virtually unchanged. Sampling at the three deep-water reservoir stations will remain unchanged with temperature, dissolved oxygen, pH and conductivity profiles collected monthly. The reservoir nutrient and phytoplankton sampling program that has been conducted quarterly since 2000 will be continued in 2006.

Table 11 - Quabbin Reservoir and Ware River Watershed Nutrient Concentrations: Comparison of Ranges from 2005 Database (1)

Quabbin Reservoir Watershed Nutrient Concentrations

Sampling Station	Nitrate (NO_3; µg/L)		Total Kjeldahl Nitrogen (TKN; µg/L)		Total Phosphorous (µg/L)		UV_{254} (Absorbance/cm)	
	Median '05	Biweekly'05	Median '05	Biweekly'05	Median '05	Biweekly'05	Median '05	Biweekly'05
West Branch Tribs								
211E	9	<5-79	193	51 – 292	11	<2.5 – 28	0.126	0.054 – 0.259
211F	12	<5 – 60	155	<50 – 362	14	<2.5 – 30	0.20	0.027 – 0.470
211G	49	16 – 138	152	55 – 283	19	<2.5 – 192	0.085	0.037 – 0.163
Hop Brook Tribs								
212A	36	<5-112	219	91 – 305	20	<2.5 – 32	0.148	0.068 – 0.254
212B	72	27-128	145	52 – 387	16	<2.5 – 56	0.122	0.056 – 0.217
Middle Branch Tribs								
213A	53	12 – 170	261	56 – 367	22	<2.5 – 32	0.207	0.085 – 0.430
213B	45	13 – 178	164	<50 – 359	18	<2.5 – 42	0.21	0.088 – 0.437
Core Sample Sites (2)	Median '05	Quarterly '05	Median '05	Quarterly '05	Median '05	Quarterly '05		
211 (W. Branch)	49	<5 – 104	215	98 – 356	14	<2.5 – 28		
212 (Hop)	68	29 – 87	222	114 – 421	18	<2.5 – 59		
213 (M. Branch)	8	<5 – 83	283	186 – 430	23	8 – 32		
216 (E. Swift)	33	27 – 89	223	211 – 448	24	11 – 60		
215 (E. Fever)	52	<5 – 207	302	203 – 618	21	11 – 46		
Boat Cove Bk	34	<5 – 108	237	174 – 274	31	14 – 37		
Gates Brook	6	<5 – 14	127	90 – 188	15	9 – 23		

Notes: (1) Initiated nutrient sampling in March 2005.
(2) 2005 quarterly sampling conducted March, July, August, September and November.

Ware River Watershed Nutrient Concentrations

Sampling Station	Nitrate (NO_3; µg/L)		Total Kjeldahl Nitrogen (TKN; µg/L)		Total Phosphorous (µg/L)		UV_{254} (Absorbance/cm)	
	Median '05	Biweekly'05	Median '05	Biweekly'05	Median '05	Biweekly'05	Median '05	Biweekly'05
108A W.R.	24	<5 - 71	343	215 - 636	21	<2.5 - 64	0.261	0.155 - 0.488
108B W.R.	72	7 - 111	486	209 - 728	19	7 - 46	0.252	0.110 - 0.325
108C W.R.	34	<5 - 209	196	58 - 262	11	<2.5 - 16	0.085	0.057 - 0.129
116 W.R.	23	<5 - 31	230	143 - 222	15	<2.5 - 16	0.226	0.040 - 0.084
116B W.R.	<5	<5 - 17	367	175 - 809	30	10 - 112	0.352	0.157 - 0.859
Core Sample Sites (2)	Median '05	Quarterly '05	Median '05	Quarterly '05	Median '05	Quarterly '05	Median '05	Biweekly'05
Shaft 8	25	<5 - 49	278	266 - 371	27	13 - 41	0.286	0.166 - 0.544
108 W.R.	22	15 - 35	232	239 - 536	16	14 - 49	0.269	0.158 - 0.468
121A W.R.	<5	<5 - 12	369	248 - 490	17	13 - 22	0.255	0.119 - 0.342
103A W.R.	25	10 - 30	314	188 - 462	32	12 - 43	0.263	0.154 - 0.458
107A W.R.	23	<5 - 109	422	287 - 506	44	21 - 57	0.397	0.248 - 0.758

Notes: (1) Initiated nutrient sampling in April 2005.
(2) 2005 quarterly sampling conducted April, August, September and October.

References:

American Public Health Association, 1998. Standard Methods for the Examination of Water and Wastewater - 20th Edition. Washington D.C..

Garvey, E.A., Tobiason, J.E., Reckhow, D.A. and Edzwald, J.K.. October 2000. Natural Organic Matter Fate and Transport in Quabbin Reservoir. Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst.

Lee, Yuehlin, February 2004. Total Coliform Trends in Quabbin Reservoir, 1995-2002. Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst.

MA Executive Office of Environmental Affairs, 1999. MA Geographical Information System.

Metropolitan District Commission, 2005. Meteorological and Yield Data Records. MDC unpublished data.

Shanley, J.B.. 1994. "Effects of Ion Exchange on Stream Solute Fluxes in a Basin Receiving Highway Deicing Salts." Journal of Environmental Quality, 23:977-986.

Streeter, H.W., 1934. "Formulation of Bacterial Changes Occurring in Polluted Water." *Sewage Works Journal*, Vol. 6, No. 2.

U.S. EPA, 2000. Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria. Office of Water.

Wolfram, Evelyn. May 1996. Determination of the Decay Rate For Indicator Bacteria Introduced by Sea Gulls to an Oligotrophic Drinking Water Reservoir. M.S. Thesis, Department of Civil and Environmental Engineering, University of Massachusetts at Amherst.

Worden, David. 2000. Nutrient and Plankton Dynamics in Quabbin Reservoir: Results of the MDC/DWM's 1998-99 Sampling Program. Metropolitan District Commission, Division of Watershed Management.